Using cognitive cases to establish incidence: The case of exaptative actions

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Abstract

The primary methodological approach in cognitive psychology is experimental. However, the case study seems to hold particular importance in the foundational concepts of higher cognitive functions. For example, theories of the cognitive changes that lead to spontaneous insights have their roots in moments such as Poincaré's realisation about chaos theory while stepping onto a bus or Kohler's description of the ape Sultan's sudden discovery of how to reach a banana. Indeed, it makes sense for research that is interested in nonstandard cognitive processes to be founded on case studies. In this paper, we draw on detailed examination of single cases to illustrate exaptative actions. Exaptative actions are actions which have an initial goal not related to changing the problem space in an epistemically or pragmatically amenable way but accidentally reveal a pathway to the problem solution. We show that these actions are a common bridge between pragmatic and epistemic actions but also question the idea that there are easily identifiable distinct action forms over the course of a problem-solving episode. We finish with observations on the importance of qualitative, single case research to cognitive psychology.

Keywords: Case study; Exaptative actions; Insight; Cognitive psychology; Problem-solving.

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Cognitive psychology is primarily concerned with understanding how people *think*. It arose in the 1960s as a reaction to behaviourism and had as its initial focus the role of mental representations in thinking and a commitment to a computational approach (Núñez et al., 2019). In other words, it was concerned in the main with processes that are theoretically invisible and often subconscious (Ball & Ormerod, 2017) and, to date, tends to assume that these processes are conducted internally. Although these commitments to representationalism and computationalism have been somewhat attenuated with the rise in alternative theoretical positions (see Bruin et al., 2018; Menary, 2010 for overviews), the role of sub-personal and invisible processes is still key to cognitive theories and explanations. For example, the most recent definition of the creative process defines creative cognition as “internal attention constrained by a generative goal” (Green et al., 2023, p. 11)

The dominant approach in cognitive psychology is heavily reliant on elegant experimental and quantitative methods as providing a “gold standard” of evidence (Goel, 2019; Mandler, 2011; Rosenbloom & Forbus, 2019) for tracking these sub personal and invisible processes. Crucially, this tradition is undergirded by the foundational belief in a unity of the thoughts and actions that support intelligent behaviour (and indeed the unity of what constitutes intelligent behaviour), which leads to experiments that generate data aggregated across participants to elucidate commonalities in thinking processes rather than identifying idiosyncrasies in human thought (Simon, 1965). This averaging assumes that cognition is driven by a broadly normative architecture that remains stable across people and can be understood meaningfully in isolation from environmental influences. An implicit assumption of this theoretical position is that, because experiments are administered in a controlled environment and manner, environmental influences are controllable (Fodor, 1980; Ross & Vallée-Tourangeau, 2021c).

It is this tradition which serves as the testbed for research in problem solving from the perspective of cognitive psychology. Heavily inspired by Newell and Simon's General Problem Solver (1972), research in this domain tends to look for linear atomised processes. For example, the Creative Problem Solving model (Treffinger, 1995) consists of four main processes – understanding the problem, generating ideas for solving the problem, preparing for action and planning an approach. Although it is not stated explicitly, there is the same underlying divide in the model between idea generation and action/implementation that we see in other models in this tradition that have a sharp divide between thinking and acting. This divide between the ideation and implementation runs contrary to research in other domains where we see that action and idea generation are closely related and interwoven. For example, Schön (1992) develops a computational model based in the tradition of design which heavily forefronts this interaction between mind and material including the designer "seeing-moving-seeing". Similarly, qualitative work with creative people across different domains document the importance of interaction with the world as part not just of making but of thinking (Glăveanu et al., 2013; Malafouris, 2014; Ross & Groves, 2023).

To isolate even further the cognitive processes of interest, tasks in classic problem-solving research tend to be artificial, knowledge lean and well defined. For example, the classic river crossing task presents problem solvers with a farmer on one side of a river with a fox, a chicken and a bag of grain. There is a boat which can take the farmer and one other piece of cargo. The problem requires the problem solver to move all three items across the river with the constraints that if the fox is left alone with the chicken on either side the fox will eat the chicken and similarly if the chicken is left alone with the grain that will be eaten. The task is well structured with each element clearly demarcated (Reed, 2016; Simon, 1977).

Similarly, much contemporary research into insight problem-solving draws on Compound Remote Associates (c-RAT) tasks (Bowden & Jung-Beeman, 2003), where the participant is given three related words and is asked to find the common link. These types of problems are also relatively knowledge lean – that is, they do not require additional knowledge beyond the problem statement and a level of linguistic knowledge of the average well educated person[1]. Such characteristics are often used as descriptive of the problem, but it is important to note they are also assumed to be characteristics of the problem solver. It makes specific and often implicit assumptions about what constitutes knowledge and what knowledge might be transferable or useful. Indeed, these assumptions about the epistemic and motivational state of the participants undergird much of the experimental work in this area.

Tasks such as the river crossing and c-RATs are selected to isolate the cognitive processes of interest, and broad assumptions are made about possible cognitive processes and pathways based on logical and normative data. This is not just a methodological but also a theoretical commitment: Abstract thinking is prioritised. These experiments take place in what Vallée-Tourangeau and March (2019) call a second-order environment, that is, one which is one step removed from the concrete. The answer to the river boat conundrum is not to shoot the fox, which is arguably the best answer in the circumstances (see Ross, 2024, for a fuller discussion of normativity in establishing correctness). Instead, there are unarticulated constraints as well as those present in the problem statement; the participant is aware that they are operating in a certain environment. This leads to the conclusion that the cognitive processes that underly this form of highly intellectualised *thinking* are, by and large, atomised and linear and marked by intentionality and rationality (De Jaegher, 2019; Pernu, 2017).

[1] There is not a clear definition of what constitutes an average well educated person and while many of the research subjects end up being psychology undergraduates, there is a wide variation in these. This is a neglected area in part because of the modular and nomological approach which seeks to flatten difference in search of universal laws.

Performance can therefore be aggregated across multiple trials, and this performance is hypothesised to reflect an underlying cognitive architecture independent of the individual (Ohlsson, 2011). Indeed, this aggregation is especially encouraged in the case of "highly idiosyncratic" problems (Chuderski et al., 2020, p. 5) such as the class of problems known as insight problems (see below) to deliberately smooth out inconsistencies. This is a theoretical decision, even if the field often does not consider it to be so (Jamieson et al., 2023; Noë, 2010).

Case Study Research in Cognitive Psychology

The focus on experimental simplicity and aggregated means has led to a lack of single case designs in cognitive psychology, aside from those reliant on a large number of trials across individuals (e.g., in psychophysical studies of perception). Such multi-trial and multi-participant designs necessarily limit the complexity of the tasks and exclude higher order cognitive processes that extend over longer latencies. However, we argue that there are benefits to the detailed study of single, non-aggregated cases, especially when the research interest is in higher, complex cognitive processes which are unlikely to have a single, easily controlled causal chain. Certainly, within creative cognition research, many of the foundational *concepts* stem from case studies that are later tested in large trials. Take for example, research on insight which draws from two key case studies – Köhler's (1925) detailed examination of ape behaviour and Poincaré's account of his flash of insight stepping onto a bus (reported in Wallas, 1926). One was a detailed observation of an experimental situation and the other was a retrospective self-report, but they described and defined a phenomenon in a way that is still being used 100 years later (see for example Danek, 2023).

Other disciplines have continued to draw on detailed case study analysis. For example, the method of microgenetic analysis is common in the learning sciences to fully understand change processes by drawing on dense and detailed observation (Siegler & Crowley, 1991) and there has been a detailed understanding of how learning (including problem-solving) unfolds over time and in interaction. However, research in the problem-solving tradition has moved away from the case study to typically focus on experimental designs with larger samples that tend to take place in a sterile environment – either the psychologist's laboratory or, increasingly, online (Vallée-Tourangeau & March, 2019). This paper is a call for those traditions to borrow from their close cousins to expand understanding of how problem-solving happens in a richer environment than psychologists' laboratories.

One way in which a detailed granular analysis of individual participants can add to our understanding of a phenomenon is to assess the extent to which the outcome measures reflect the hypothesised causes. The granularity afforded by a deeper level of analysis allows us to be more exact about the reasons for any effect detected in the larger population. For example, in Vallée-Tourangeau et al. (2020) participants were invited to solve the triangle of coins problem (to invert a triangular array of 10 coins by moving three coins only) in two conditions: one with a two dimensional image of the problem (a low interactivity condition) and one with moveable coins on a screen (a high interactivity condition). Crucially, they were only allowed one guess[2] at the solution. While the movable interface yielded more successful trials, those trials were significantly slower. Traditionally, a longer latency to solution indicates higher cognitive effort. However, a qualitative evaluation of video material showed that participants would solve the problem quickly in the high interactivity condition. However, because the interface afforded them an easy opportunity to check their answer, they would take advantage of this, build the solution a second time and so increase their latency to submitting a solution. Latency for the low interactivity condition measured time to mentally

[2] In Experiment Two; in Experiment One they were allowed unlimited guesses.

generate a solution, whereas for the high interactivity condition it measured time to solution and to verification. So, while the condition was the cause of the difference in latency, case study analysis revealed how the affordance of the interactive display enables a choice of strategy that impacts on latencies. In other cases, such as that illustrated by Cushen and Wiley's (2012) individual analysis of participants' solution patterns, solvers demonstrated patterns which were contrary to the overall trend of their condition but were obscured in the aggregated data. As they write (p. 1171) "this finding highlights the danger of making global assumptions about solution patterns from aggregated data, as that data may not be representative of all participants' actual restructuring".

The sampling procedure can be targeted. For example, in Ross and Vallée-Tourangeau (2021a), outliers from the general trend were identified and closely analysed to understand the boundary conditions of success or failure in a word production task. Participants were given a set of letters in either a high interactivity condition with movable tiles or one where they were restricted from moving the tiles, alongside one where the tiles could be randomly shuffled but not arranged. In this study, they undertook a close analysis of a participant who performed best in the high interactivity condition and one who performed worst, to allow a detailed analysis of the behaviours that led to success and failure in this condition. A granular analysis showed that the higher performer spent significantly more time interacting with the tiles while the low performer hardly touched them. In Ross and Vallée-Tourangeau (2022), the cases were selected at random as part of a pre-registered mixed methods analysis plan. Participants solved anagrams either by moving lettered tiles or by shaking them up and breaking fixations. Pre-planned case study analysis allowed the authors to understand why their initial quantitative hypothesis – that random shuffles would support solving – was not upheld, detailing the way that lucky shuffles were not actively noticed.

This allowed a theoretical advance that active agency is an important part of the interaction with accident.

As well as acting as explanatory aids, case studies can also be used to generate empirically motivated hypotheses or illustrate the existence of cognitive phenomena of interest without making a claim for generalisability. Steffensen (2016) advances the case for a focus on individual cases, both as a way of generating principled and empirically grounded hypotheses and as a way of understanding intelligent behaviour as a part of a multilayered cognitive ecosystem. In this way, close and detailed observation prior to experimentation can facilitate our theorising and allow the identification of unanticipated variables. The role of case studies is very different methodologically and theoretically from traditional experimental cognitive psychology. It draws on methodological principles that Steffensen (2016) calls probatonic, referencing biblical assertations of the importance of tending to a single sheep among the flock. As Steffensen writes (p. 30) “the [probatonic] principle's importance lies in the fact that it forces us to attend to small, nonlinear (and at times one-off) phenomena that (also) impact on behaviour”. In other words, illustrative case studies can draw our attention to factors that flesh out our understanding of behaviour and generate more complete hypotheses. This is something that is often done informally through observation and even reported as such in the discussion sections of research articles. As Steffensen argues, there is often a qualitative case study aspect that underlies hypothesis generation, but this is rarely examined. A detailed case analysis allows for more empirically rigorous hypothesis generation (see also the argument in Ross and Vallée-Tourangeau, 2021b).

Extended Approaches to Problem-Solving

Problem solving has typically been seen as a foundational activity for the rational cognizer and so it is a core research area in the study of thinking and cognition. It is considered to be an example of effortful contemplation, the research area which also encompasses reasoning, judgement and decision making. Alongside being a foundational domain for traditional theories of cognition, problem solving has also been exploited as a testbed for theories of extended and interactive cognition. In these theories, representation-heavy higher-order cognition has been demonstrated to be in some way dependent on the external environment (Kirsh, 2009; Vallée-Tourangeau & Vallée-Tourangeau, 2020). However, across these theories of problem-solving, from traditional internalist computational accounts to approaches that emphasise the importance of the extended mind, the agent is still considered to be reflective and rational. For example, in theories of interactivity, the problem-solver actively recruits the problem-solving environment to scaffold a problem-solving strategy. For this reason, we see fallacies relating to the omniscient problem solver who is hypothesised to use the environment in a way which always advances the best pathway to success (Ross & Vallée-Tourangeau, 2021c) or erroneous assumptions that the environment is always a positive cognitive scaffold (as described in Bruineberg & Fabry, 2022).

In other words, a science of problem solving assumes that, if a problem can be solved without conscious contemplation or “thought-full” ness, then it is not a problem of interest because problem-solving is not of interest in itself, but rather functions primarily as a tool to elicit certain types of contemplative behaviours (Simon, 1965). The solution or otherwise of a knowledge-lean problem is not in itself of interest, but the processes – planning, insight, etc. – it elicits are. These processes are all assumed to stem from a rational and structured approach to the problem. The data we present here suggest that the story is more complex and that interactions with the environment can be messy and proceed, not so much from planning, but from play and thoughtless movements. We present these data, not to establish a generalisable reliable mechanisms for problem solution, but as a cautionary note that the underlying processes may be necessarily dependent on complexity.

Newell and Simon (1972) suggest that all problems demonstrate three basic features: an end goal, a starting state and a set of possible actions which could transform the starting state into the end goal (see also Gilhooly, 2019). In terms of problem types, analytical problems are those where the pathway to the solution is clear, if at times arduous, and the set of possible actions is made clear in the problem statement. These problems lend themselves to an easy path analysis and it is generally assumed that a normative answer is generated by a normative process (normativity here is defined in terms of optimality, namely the minimum number of moves required to traverse the problem space efficiently from start to finish). Insight problems, on the other hand, require an abductive leap (Ross & Arfini, 2023) – sometimes the goal state is already present (such as the triangle of coins problem) but the route to that end state is obscured, so the *route* becomes the target for solution. Other times, the end state is not obvious and nor is the pathway to the solution. However, insight problems are also often simple, so the pathway and the end state are uncovered by the problem solver at the same time. Sometimes this is accompanied by a clear phenomenological marker[3] (so called 'aha') and other times not. In other words, an insight problem is one which does not adhere to a typical normative model of problem-solving and requires different models. Insight problems struggle to be contained by models which rely on a series of rational steps precisely because they require the type of thinking which does not follow those steps (Ohlsson, 2018).

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[3] Initially, insight problems were conceived as being structured in such a way that it was presumed that they could only be solved through insightful processes. However, a closer attention to the phenomenological markers by researchers such as Bowden (e.g. Bowden et al., 2005) and Danek (e.g. Danek et al., 2014) has led to these markers becoming the measure of the 'insight' experienced and theoretically required to solve the problem, thereby shifting the process to the individual rather than as a necessary property of the problem itself (Webb et al., 2016). The phenomenology of insight is typically theorised as multifactorial and participants are requested to rate how they felt during or after solution across five dimensions: happiness, certainty in the solution answer, surprise at coming across the answer, the suddenness of the answer and the level of impasse they experienced. A higher score represents a more insightful experience and is taken as an indication that the problem was solved using "insight" (Danek et al., 2020). It is not clear how the granular measure (participants are often asked to map feelings on scales of 0-100) maps onto a binary insight/not insight outcome.

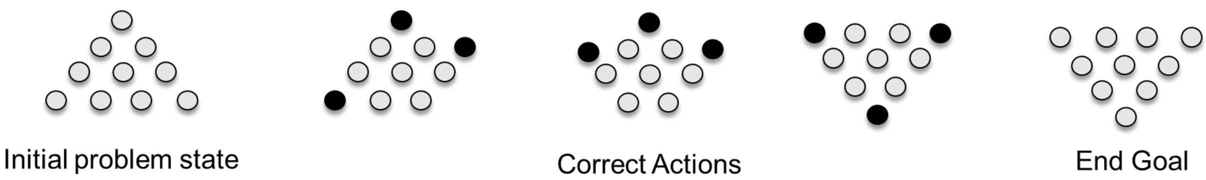
Despite uncertainty about the process, we can draw clear distinctions about the nature of the ignorance faced by the problem solver. With analytical problems, while the answer is unknown, the process of getting to the answer is clear and known. For example, with something like mental arithmetic, while the problem solver may not know the solution, they may know the operators and rules that correspond to the most efficient process. These steps will have been already predetermined culturally and through personal experience. Therefore, it is likely that the agent will eventually select the correct objects and the correct actions over those objects. Indeed, the accuracy of the solution in the eyes of the problem solver is not clear in itself but is predicated on an accurate following of the steps. Trust in an answer to a mental arithmetic problem comes about, not because of the answer itself, but because we trust in the steps that led to the answer.[4]

For some insight problems, the goal state is given but the method of reaching the answer is unclear. Take for example, the triangle of coins problem (e.g., F. Vallée-Tourangeau et al., 2020; Figure 1). This problem presents the solver with a triangle composed of coins arranged in such a way that the triangle points up. The task is to change the orientation of the triangle so that it points down by moving only three of the coins (Metcalfe, 1986). The end state is clear and easily recognisable. In this instance, the process is not relied upon as an accuracy check as it is in analytical problems. Rather, the answer is easily recognised as being correct and functions as its own check. You can "see" that you are right.

[4] This is not to undermine the abilities of those who sense check whether an answer is correct or not but rather to emphasise the difference between a problem where the process becomes unimportant once the answer is generated because the answer is clear in itself and one where the answer is predicated on a correct, linear process.

Figure 1

The Triangle of Coins Problem and One Possible Solution Which Involves Moving the Bottom Vertices up and the Top Vertex down. [5].



However, in many ill-structured or non-analytical problems, the problem solver is in double ignorance: They do not know the correct solution or the manner of approaching the correct solution. In terms of extended mind theories, this means that they will not necessarily select the correct objects or actions over them but merely those that satisfy the needs at the time (MacGregor et al., 2001; Ormerod et al., 2013). Progress in solving insight problems requires satisfying local demands towards a predetermined criterion and posits a limited ability to look ahead. Incremental progress can lead away from the direct goal while fulfilling the demands of the current criterion. When satisfying these local demands is reified in the problem environment, it can lead quickly to impasse or fixation.

For this reason, it is likely that there cannot be a straightforward recruiting of the environment in insight problems. The problem-solver does not know what to do and so will have to play and experiment more with the problem elements. This playfulness has been remarked upon anecdotally by several researchers in this tradition. Fioratou and Cowley

5 There are actually two ways of solving this problem. The first (translation across the median) is illustrated in Figure 1 and the second involves a rotation of the vertices while leaving the central rosette untouched, the rotational solution. For a fuller discussion of these two options see Vallée-Tourangeau et al. (2020).

(2009), for example, describe a version of the cheap necklace problem[6] and suggest that 6 of the 21 solvers (almost a third) solved the problem through the exploitation of an accident in which lengths. This same observation is made by Chuderski et al., (2020, p. 18) who suggest that "in the matchstick algebra problem[7], it is arguably easier to arrive at the solution by accident or trial and error, for instance by realizing as a result of a random movement of a stick that it could act as a negative sign". Such playfulness is only possible in an experimental set up where the participants can move and interact with the environment and it is notable that, when such interactivity is offered, it elicits this behaviour (see also Ross & Vallée-Tourangeau, 2021a). To date, there are no models of insight problem-solving that take the environment into account in this way, suggesting that these observations are not being taken seriously as potential causes of the moment of insight (although see Ross, 2024a).

Actions: Pragmatic, Epistemic and Exaptative

Kirsh and Maglio (1994) argue that actions on the world can have an epistemic rather than pragmatic function. Using the example of a Tetris player spinning a zoid, the authors demonstrate how the classic information processing model cannot account for the way that actions generate knowledge. Instead of a model of action that requires planning before action, the data suggest that rotations in the world act to improve the epistemic state of the player by reducing "the pace, time or unreliability of the computations" (p. 527). These actions change the input to the processing system. From the experimental data, Kirsh and Maglio extract two sorts of actions that can be performed on the array: Pragmatic actions, which are movements

[6] The cheap necklace problem is as follows: A necklace has broken into four segments, each of three chain links. The task is to mend the necklace spending a maximum of £15, under the constraints that it costs £2 to break a link and £3 to join a link. The solution requires breaking one of the segments into three unlinked pieces, and then joining the remaining segments using these unlinked pieces.
[7] Matchstick algebra problems are those in which an arithmetic sum is presented in the form of matchsticks laid out as Roman numerals. The task is typically to move one stick to make the sum arithmetically correct. For example, the problem III = III + III can be solved to form the tautologous but numerically correct expression III = III = III.

towards a goal, and epistemic actions, which make no practical advances in the problem space but reveal information and so advance the epistemic state of the participant. The divide between the two is perhaps best illustrated by a navigator taking a boat around an island[8]. To navigate successfully around the island requires hugging close to the coastline, a pragmatic action. However, to get a better sense of positioning relative to landmarks on the island, the navigator may sail further out to sea. This is an epistemic action that holds no purpose in terms of progress, indeed quite the opposite as the boat moves away from its goal, but it advances by changing the epistemic landscape. Kirsh and Maglio point to the superfluous moves made by Tetris players that did not advance the players pragmatically but did advance them epistemically, to sustain the idea that action can yield information without needing to make a pragmatic advance. Crucially, while the existence of epistemic actions undermines the idea of planning with an already known solution, both forms of action imply an intentional agent, that is, the actions are performed with the intention of progressing to a problem solution even if the problem-solver does not yet know how to directly navigate to it.

Here, we consider a third type of action – exaptation - which describes the reuse of an existing artifact for a new purpose. It has been suggested that exaptation is an important driver of innovation because it allows for unplanned novelty to arise (Andriani et al., 2017). In this paper, we borrow the term to refer to actions that have no clear purpose related to the final goal state, but from which purpose emerges once the results are seen. Exaptative actions are different from epistemic or pragmatic actions because they decentre the human agent—she proceeds not with a plan in mind—and, importantly, the action's purpose changes through action. In this way, they differ fundamentally from epistemic and pragmatic actions. Loader (2012) problematises the dichotomy between epistemic and pragmatic by saying–

8 Example borrowed from Andy Clark in a talk given on June 17th 2020 (see https://blogs.ed.ac.uk/virtualppig/ for details), and first presented in Hutchins (1993).

"pragmatic actions are those whose primary function is to bring the agent directly closer (in a non-informational sense) to his/her goal, whereas epistemic actions are those taken for epistemic purposes in order eventually to reach that same goal." (p.222). Exaptative actions are those actions that *do not* have a goal state in mind related to the problem space, be it pragmatic or epistemic, but rather they fulfil other goals. For example, exaptative actions can fulfil sensory needs or have an aesthetic function.

In this respect, they resemble the internal activity commonly described as mind wandering. This is often closely related to creativity in the research literature, suggesting that non problem-directed actions *are* considered important when they are seen as cognitive and internal. Green et al suggest "sometimes we are mind-wandering with minimal constraint, and simply happen upon a mental representation that we only then identify as meaningful with respect to some set of end-state parameters". The difference with exaptative actions is that they are not about movements in the mind but movements in the world. They do seem to have an importance in insight problem-solving. Evidence from Fleck and Weisberg's (2013) think aloud study of insight problem-solving suggests that 11% of all solutions were generated by what they term "data driven restructuring", which is "instances when the individual changed his or her representation of the problem in response to something he or she saw from the physical configuration of the problem" (p.452). This is compared to 17% which were brought about by conceptually driven restructuring, which is the current dominant explanation for insight problem solutions.

The focus on conceptually-driven restructuring at the expense of data-driven restructuring seems disproportionate. However, despite the evidence in research literature, there has yet to be a systematic investigation of these forms of non-intentional action, so we report a study in which the characteristics of exaptative actions.Their occurrence within epistemic or pragmatic action approaches is identified and described in the context of insight problem-solving.

An illustration: Exaptative Actions

To illustrate fully the benefits of case study research in cognitive psychology, this paper will present its own case study. We present a series of cognitive cases (cf. Ross & Vallée-Tourangeau, 2021b), each of which examines in more detail the actions undertaken by a problem-solver when they are working towards problem solution (not all are successful). Our focus will be on the exaptative actions, that is, actions which do not reflect a problem-solving plan or lookahead from the outset, but which are nonetheless accidentally epistemically important, yielding information that goes on to be task relevant.

Method

Participants

Forty-nine participants were invited to take part in the study. Age and demographic data were not collected.

Materials and Measures

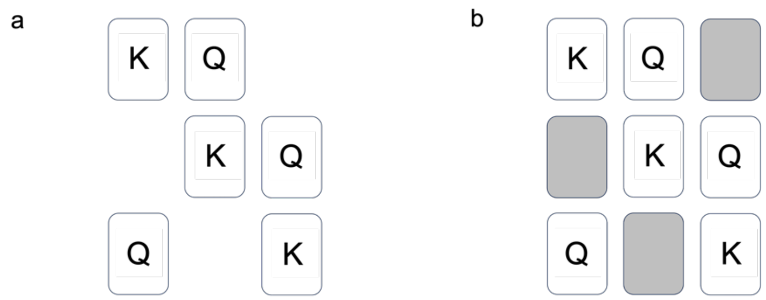
As part of a larger project, participants were invited to take part in a battery of problem-solving tasks comprised of two versions of the cards problem shown in Figure 2 (Cunningham & MacGregor, 2008), the eight-coin problem shown in Figure 3 (Ormerod, MacGregor and Chronicle, 2002), the nine-dot problem (Maier, 1930), and the triangle of coins shown in Figure 1. The case studies we present here draw on performance in two of these tasks, the KQ version of the cards problem and the eight-coin problem. Descriptions of the other tasks are included in the supplementary materials.

The Cards Problem

In the Cards problem, the task is to lay the picture cards (or other subsets of cards) from a pack of playing cards in a grid in such a way that there is exactly one card of each denomination in each row and column of the grid. Solution examples are shown in Figure 2. This is a difficult problem because, to meet these constraints, participants must build a grid that includes empty spaces, as in Figure 2(a). The problem statement does not indicate any need for spaces between cards and so the problem solver must expand their understanding of the solution space to solve. According to Ormerod et al., (under review) to solve the problem successfully, participants must discover two pieces of information – that cards can be placed diagonally and that the space between cards can vary.

Figure 2

Solution to The Card Problem (a) Without Blank Card Hints And (b) With Blank Card Hints.



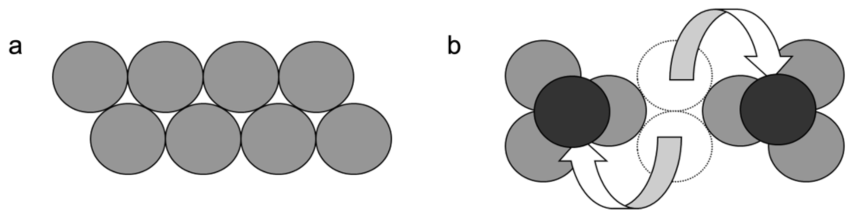
If participants are instead given nine cards (three Queens, three Kings, and three Blanks), and told that the task remains the same (to place the picture cards uniquely in each row and column), the problem changes. The blank cards function as hints to leave spaces between the picture cards (Figure 2b), allowing the problem-solver to lay out a problem solution without needing to discover the 'insight' to leave gaps between cards. Our participants were presented with two versions, one without the blank cards (KQ version) and the other containing the blank cards (KQB version). The difference between participant conditions lies in the order in which the problems were presented.

The Eight-Coin Problem

The eight-coin problem requires participants to alter an array of eight coins by moving the coins to create a final array where the coins are separated into two groups and each coin touches exactly three others. Figure 3a shows the initial problem configuration. The correct solution, shown in Figure 3b, requires taking two coins from the centre of the array and stacking one on top of each of the two resulting coin triads. In the version used for this paper, the participants were not limited in the number of coins they could move or number of movements they could make. The primary insight necessary for solving the problem is to switch from moving coins in two dimensions to considering three-dimensional moves.

Figure 3

The Initial Array of the Eight Coin Problem And Its Solution



Procedure

Participants were invited to solve a total of five problems. The battery of problems would always start and end with one of the versions of the card problem; participants asked to solve the KBQ version of the card problem first would be asked to solve the KQ version for the fifth problem, or vice-versa. For the second, third and fourth problems, the participants were asked to solve the eight-coin problem, the triangle of coins, and the nine-dot problem. To counterbalance order effects and assure randomisation, the order of the three problems in between (second to fourth problems) was randomly alternated as was the order of the card problems. All participants were given a limit of five minutes to solve each problem.

Instructions were read to participants by the researcher for each problem to ensure each participant was given the same instructions. Participants were invited to clarify the instructions before starting the problem, but only for information already provided in the instructions. The printed instructions were then placed within the participant's vision field should they wished to refer to them. The researchers made use of video and audio recordings of the participant's problem-solving process. These videos did not include the participant's face. All participants were briefed on the process, provided informed consent, and were previously informed they were going to be recorded.

Analytical Strategy

Each of the 49 participants' movements was systematically coded across various dimensions by members of the research team responsible for collecting the data. Codes were decided through deductive and inductive discussion based on theoretical assumptions and informal observations made in the course of data collection and formalised in analytical memos collected in an experimenter's notebook. Regular lab meetings throughout data collection and coding supported a collaborative understanding of the actions of interest.

In this section, we will focus on the identification of exaptative actions. The research team coded moves across all participants and trials as either pragmatic, epistemic or exaptative. Coding systematicity was assured in two ways. First, one participant was coded carefully by all the members of the research team, comparisons in interpretation were discussed in a lab meeting, and gold standards were identified. This participant served as a reference point for any subsequent coding. Second, WR checked coding of the resulting cases both spontaneously and when asked to adjudicate. The initial plan was for these findings to feed into quantitative and aggregated data sets. However, as outlined below, the distinction between the different actions was not clear enough for independent data points to be made. The decision was made for each researcher to select a critical case to examine in more depth as a way of documenting the existence and the characteristics of exaptative actions, as well as epistemic and pragmatic actions. These in-depth cases could then go on to guide subsequent coding. It is these in-depth cases that each researcher deemed to be the prototypical of this form of action that were selected and are presented below.

Each in-depth case analysed was sent to RS who consolidated the data, standardising the reporting of the cases. All cases were presented first by describing the actions of the participants, which were illustrated with snapshots of key moments. This was followed by an identification and analysis of crucial actions for the solving of the problem or actions leading to an exaptative action. If relevant, dialog and sentences thought aloud were included in the case narrative. When there was a disagreement, RS consulted WR and what is presented in this paper is the consensus. In one such case, the decision was made that during the problem-solving process no exaptative action was reached; however, the case was kept as an illustration of creative problem solving.

The case data we present represents a narrative analysis (Bakeman & Quera, 2011). The use of video in these cases is informed by a mimetic assumption – that is, that the video data in some respect represent what occurred rather than an interpretation of events (Knoblauch, 2013). However, while the researcher is theoretically in a purely observational role, we acknowledge the interpretivist nature of the analysis, especially as inferences were made about the intentions of the participant. We were supported by the act of data collection itself and the saturation in process this allowed. The analysis carried out in this section drew on grounded theory method (Charmaz, 2014; Glaser & Strauss, 1967; Urquhart et al., 2009) and we view the selection of critical cases a form of theoretical sampling both through the selection of critical cases and later through the reanalysis and revisiting of the video data.

Results

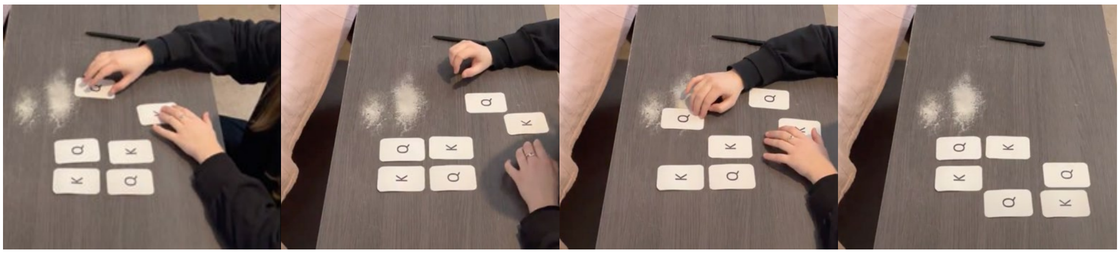
In this section, we illustrate the nature of exaptative actions and the difficulties in isolating action forms via the presentation of four cases selected by the research team and a final case that demonstrates the difficulty of fully distinguishing the action types.

Case One

In this first case, when solving the KQ version of the cards problem, participant 31 arranged the cards towards their body as the timer started running, and then laid two rows and columns each containing one K and one Q adjacent to each other, forming a 2x2 KQ grid, the other two cards being left on the side. The participant then re-read the instructions before continuing, seemingly confused as to what to do with the other two cards. They then rearranged the cards again, leaving two separated cards in a position that could potentially lead to the solution. Seemingly by chance, the position in which the two remaining cards were positioned in this intermediate state was in a diagonal configuration with spaces below and above these cards (see Figure 4).

Figure 4

Participant 31's Movement Sequence



00m09s 00m44s 01m05s 01m33s

This configuration appeared to prompt them to rethink the pattern, leading them to space out the other cards, not long after which they arrived at the solution. The described movement sequence is shown in Figure 4. The action of arranging the two 'spare' cards on the side of the 2x2 KQ grid appears to have cued the participant aware of alternative configuration possibilities. This action did not stem from an intentional epistemic move but instead echoes what Steffensen et al (2016) call an aesthetic gesture, tidying the problem space and inadvertently stumbling across solution discovery.

Case Two

Participant 57 displayed an exaptative action following a series of epistemic actions solving the same KQ version of the cards problem. As the researcher read the instructions, the participant started spreading the cards and reached a formation of approximately a grid but crucially with gaps. The participant seemed to realise the different possibilities of grid formations, as they re-checked the instructions and asked the researcher for clarification on what was meant by a grid, demonstrating by forming a 2x3 grid with all cards. After receiving clarification, they restarted the problem spreading the cards close to a grid with gaps once again.

Following a few epistemic actions – such as attempting different card formation around a 2x2 KQ grid (as in Figure 5, 01m43s) – and placing the two cards on the side, the participant mentioned that "*in a 2x3 grid…[the response]…is practically impossible, so [they] would have to try a different shape*". In other words, even though the actions did not lead to a direct problem solution, they added to the epistemic state of the participant through failure to solve. As articulated in Ormerod et al, (under review) these failures are epistemic in nature because they generate useful information about what does not work. Seconds later they reached the resolution. This sequence is represented in Figure 5.

Figure 5

Participant 57's Resolution Process

00m00s 00m17s 01m00s 01m43s 01m58s

Note. The first image represents the epistemic actions the participant performed while instructions were being read to them. The second image represents the participant clarifying the meaning of a grid. In the third image, the participant rearranged the cards after clarifying the meaning of a grid. The fourth image represents a formation that led to an exaptative action and resolution, represented by the fifth image.

It appears that spreading and playing with the cards as a preparation to start the problem, in a series of epistemic actions, allowed the participant to gather more information on different grid formations, which helped them envision further possibilities for the problem solution beyond the information provided in the instructions using what seemingly was an originally unplanned movement. The essential insight that gaps are needed was not reached through effortful *thinking* but through playing with the environment. As in Case One, we see that physically moving the two "problem" cards into a space that appears to be outside of the problem environment triggers the moment of realisation. This action is not about investigating possible pathways or even clarifying solutions, but it does reveal them.

Case Three

While solving the eight-coin problem, participant 2 started by moving the coins two dimensionally on the table, like most participants. However, they soon started holding the coins in their hand while performing a series of epistemic movements, removing them from the table and often holding them while thinking (Figure 6).

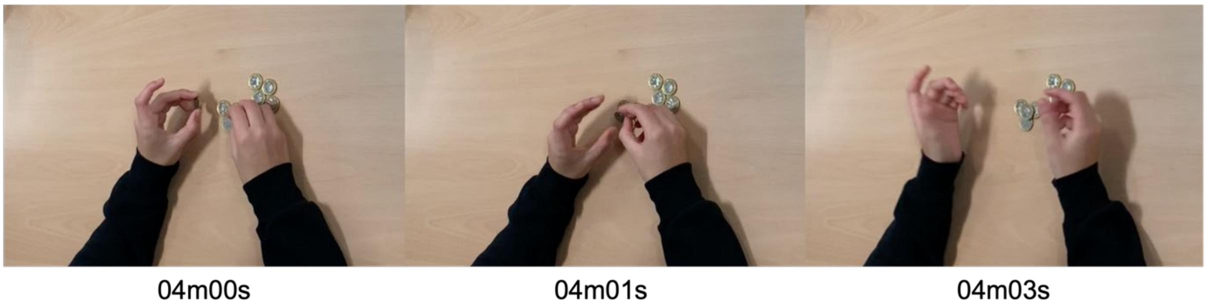
Figure 6

Participant 2's Series of Three-Dimensional Epistemic Actions

After several attempts at a two-dimension solution, the participant restarted the problem. First, the coins were separated into two groups as an initial step. Next, the participant took a coin from the table with their left hand, transferring the coin from the left to the right hand to then place it on a base of three coins arranged as a triangle to reach the solution (Figure 7). This transfer between hands suggests that this coin was initially taken off the table, not as a pragmatic movement with the intent to attempt the final resolution, but rather as unintended fiddling that became an exaptative action analogous to movements seen on previous cases. Discovering three dimensionality was a necessary step to help reach the resolution. In this example, the participant first extended beyond two-dimensional movements by holding the coins in epistemic actions. However, as the final movement used an exaptative action to reach a solution, the exaptative action soon became a pragmatic one.

Figure 7

Participant 2's Exaptative Action Sequence to Solution



Case Four

Participant 53 demonstrates a moment of exaptative action while attempting a solution to the eight-coin problem. As most other participants, the participant started moving the coins two dimensionally. However, after a few attempts, the participant split the coins into two groups and paused to think. While thinking, they grabbed some coins and started piling them up, seemingly for no reason other than as a form of aesthetic action, as seen in Case One. Their movements were considerably slower than their previous pragmatic movements, perhaps indicating they did not have an end goal in mind. However, before putting the last coin of the group on top of the pile, the participant seemed to realise the possibilities of new arrangements, changing the action and placing the coin next to the base, sequentially adding more (Figure 8). Once again, here an exaptative action was preceded by epistemic ones; these then became pragmatic as the participant tried different combinations around the pile and reduced the coin count in the pile.

Figure 8

Participant 53's Coin Pile Sequence

01m31s 01m41s 01m48s 02m12s

Note. The images display the sequence described above with the exaptative action taking place on the second image.

After separating the coins into two groups of four, the participant picked up a coin from one group and held it above the other group, close to approaching a solution. Then, the participant placed one coin partially lifted on top of two others. Seconds later, they moved the existing lifted coin and placed another coin, leaving one coin partially lifted on top of each of the two on the table. After counting, the participant reverted to one coin lifted on two other coins, followed by sliding the lifted coin to stay fully on top of the two other coins (Figure 9).

Figure 9

Participant 53's Movement Sequence after Exaptative Action

03m24s 04m25s 04m41s 04m51s

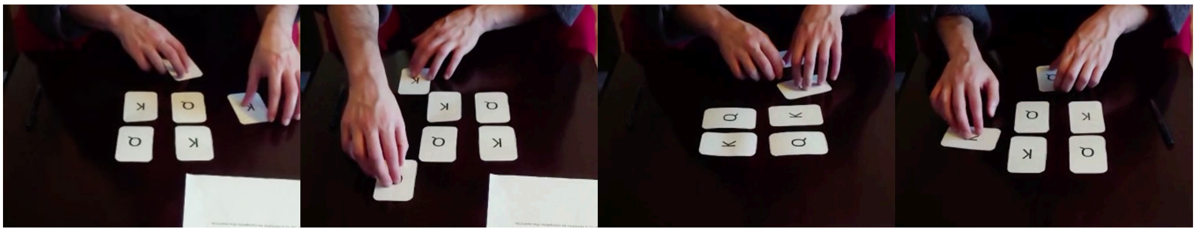
The participant restarted the problem a few moments later; however, with no success within the given timeframe. Within the problem-solving process, counting, moving around, and holding the coins led to near solutions. This sequence presents epistemic actions such as the initial stacking of coins, which extended beyond the two dimensionality of movement leading to the exaptative action, followed by further pragmatic actions using three dimensional movements.

Case Five

In the final example, participant 56, like most participants when solving the KQ problem, first created a 2x2 KQ grid, leaving them with two cards with which they performed a series of epistemic actions (Figure 10).

Figure 10

Participant 56's Series of Epistemic Actions



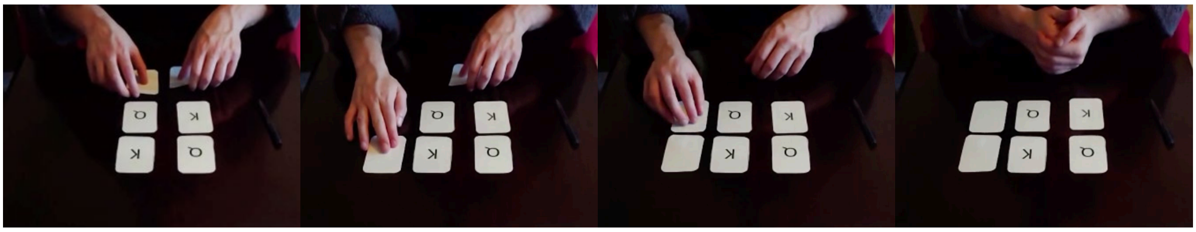
00m27s 00m43s 02m29s 04m03s

Note. The images from this figure exemplify some epistemic movements within the course of the entire problem-solving process.

The participant seems to have concluded that the solution with the number of cards provided was not possible as they then took one of each card and set them aside to later flip them facing down, reducing the visible K and Q count to attempt a solution (Figure 11), demonstrating a creative problem-solving process as a result from a series of epistemic actions. However, when the participant presented such solution asking the researcher "*is this okay?*", the researcher encouraged the participant to "*keep trying*", indicating that was not the resolution required.

Figure 11

Participant 56's First Solution Attempt



04m19s 04m22s 04m25s 04m33s

After discarding the initial solution using the two upside-down cards, the participant repurposed the reduced set of visible cards by positioning two cards on top of two corresponding others (Figure 12). These actions simplify the problem and introduce new solution possibilities. In both situations, the participant reconfigured the card arrangement to meet the problem criteria, showcasing a form of creative problem-solving. However, these answers were not normatively correct.

Figure 12

Participant 56's Second Solution Attempt by Repurposing the Extra Cards

05m06s 05m07s 05m08s 05m09s

They used the cards in ways not initially intended to arrive at a solution to escape the impasse of the 2x2 KQ grid formation, such as finding creative solutions to limit the number of cards to eliminate the extra two cards by turning the cards upside-down or superimposing matching cards. These actions were blindly epistemic, using action to reduce or understand the problem state. It is worth noting that, in the absence of an exaptative action, the participant failed find a solution.

Discussion

From the detailed examination of the cases above, the notion of exaptative actions can be defined through three observations drawn from across the dataset.

1. There is a distinction between exaptative, epistemic, and pragmatic actions but it is complicated

In a problem-solving context, exaptative actions are linked to either epistemic or pragmatic ones. By definition, they are a turning point in the purpose of an action. Epistemic and pragmatic actions are approaches in which the participant engages to make movements and advance knowledge; these movements will either be ones that are directly guided towards the goal – a pragmatic movement – or different and sometimes random movements that allow the participant to gather information and advance knowledge – an epistemic movement. An exaptative action has its genesis in another action (whether epistemic or pragmatic), making the distinction between the two at times blurred. It may occur within a period of epistemic action, commencing seemingly unconsciously but often being sequentially transferred to consciousness as it generates following pragmatic actions. Thus, exaptative actions are contingent upon, but notably distinct from, the other action types.

However, the coding of the different types of action was not conducted easily and collapsed at certain times. During the initial process of quantitative coding, each participant's moves were blind coded by two researchers. However, at times this primary coding and distinction was unclear, leading to inconsistency in coding. This led to the realisation that the movement coding was more nuanced and complex than initially anticipated. This complexity in movement definition is what guided our change in the analysis strategy to a more granular, qualitative approach.

2. Exaptative actions trigger a switch from predominantly epistemic to predominantly pragmatic actions.

In examples 1-4 above, when resolution or near resolution was reached, the exaptative actions were preceded by epistemic actions and followed by pragmatic actions. However, the transformed actions from which exaptative actions originated were mainly unintentional, such as fiddling and tidying. In a problem-solving context, as exaptation is the repurposing of an action, it is as though exaptative actions are followed by sudden or progressive perspective change, which consequently helps the participant reach the solution. These changes, when the solution is found due to exaptative action, are sudden “aha” moments which are characteristic of insight; when the solution is not found seconds after the exaptative action, the perspective change is still present, but a series of further actions (often pragmatic) are needed subsequently. Both, however, are preceded by one or more epistemic actions that pave the way and allow the exaptative action to take place. Importantly, epistemic actions seem to elicit unintentional movements that are fundamental to the following exaptative actions. This is because these unintentional movements were often the ones later transformed into exaptative actions themselves. Such movements were not observed in the context of ongoing pragmatic actions.

3. Time and familiarity with previous actions are needed for exaptation to happen

Participants who reached the solution performed a movement early in the problem-solving process that would later become an exaptative action. For example, for participant 2, this type of movement happened for the first time 1 minute and 7 seconds from the start of the problem in an exercise that lasted a total of 4 minutes and 3 seconds. This allowed a total of 2 minutes and 56 seconds of exploration after first extending beyond two-dimensional attempts, approximately 72% of the total time taken to solve the problem. The same is true for participant 31, from which the time-distance between the relevant movement and resolution accounted for 90% of the total time. Participants 53 and 56 did not reach a resolution, and participant 57's first movement was to rearrange the cards closely to a grid with gaps while instructions were still being read, which would account for 100% of the time between exposure to relevant movement until resolution.

This suggests that, for an exaptative action to take place, a certain familiarity with the previous action being transformed must exist. This echoes the case study outlined in Steffensen et al. (2016). In their case, the participant was tasked with the 17-animal problem, which invites participants to solve the problem of placing 17 animals in four pens such that there is an odd number of animals in each pen. The solution involves overlapping the pens so that one animal is in two pens. In the case study from Steffensen et al, this overlap happened as the result of an aesthetic or tidying gesture. Crucially, it happened twice before it was noticed.

General Discussion

By the definition synthesised here, exaptative actions are the transformation of the purpose of one action into another. Intentional actions (pragmatic and epistemic) and non-intentional movements (e.g., fiddling, tidying) in the problem-solving exercises provide three movement types that could become an exaptative action. Pragmatic actions, being focused on a goal that has already been conceived, might limit the individual's openness to possibilities. Conversely, epistemic actions focus on epistemic possibilities and happen in a space of ignorance. In the case studies, the non-intentional movements that often generated exaptative actions happened within the context of a series of epistemic actions. However, this does not rule out the possibility of pragmatic-exaptative actions, as the realisation for a purpose change while performing a pragmatic action is possible, but less likely due to the possibly restricted goal-directed nature of the pragmatic action. There is no good reason to change course if you are already advancing towards the answer.

Of course, we have also demonstrated that there are problems with a strict divide between epistemic and pragmatic actions. One of these is one identified by Loader (2012): cognitive processes are necessarily sub-personal and so interpretation requires inferences about intention. Above, we have made several informed inferences about participants' intentions and the meaning of their actions. Additionally, based on the case studies, inference about the nature of the effect of each approach to problem-solving movement (namely, epistemic or pragmatic) in expanding or limiting cognition and creativity was made, but further studies are needed to explore these claims. The interpretation and generalisability of results presented here in regard to cognitive processes should be done with caution. Similarly, by dividing certain actions into different types we have constructed categories that are not natural kinds; the action types we have identified are simply one of a number that could be carved out of the movement flow.

However, we have demonstrated what a granular analysis of individual cases can illustrate about different approaches to actions in problem solving. Exaptative actions were used to illustrate complex high-level cognitive processes, such as the actions that interplay in problem solving, which would have not been identified in aggregated means in simplified experimental research and large trial numbers. As such, case studies are valuable study methods to investigate and identify incidence in circumstances where generalisation and replicability are not the focus of interest. Scientific models are necessarily abstracted models of the "real world" and the art lies in knowing what to include and what to exclude. Qualitative and observational research can serve as a useful check that all important mechanisms are accounted for. In other words, this research embraces a notion of "controlled sloppiness", that is, understanding that within the boundaries of experimental control there are spaces for unexpected understanding of unconsidered hypotheses (Grinnell, 2009). The observations reported here could not have happened unless the participants were placed in a situation where they were allowed to interact physically with components of the problem statement. There is emerging evidence that, in a digital environment that does not allow interaction or offloading, people do not spontaneously recruit the environment but also tend to do worse (Ross & Arfini, 2024). This is an important consideration as research in problem solving psychology moves increasingly online.

The use of case studies is not antithetical to the foundations of creative cognition research. As we outlined above, the very phenomenon of insight is founded on two case studies that are still used today to support our understanding of how problem solutions can come to mind without a full understanding of the process underlying that solution. The cases we report demonstrate that this process can happen outside the head as well as inside it. Actions on the world can be supportive when decoupled from an intention. However, the non-linear nature of these actions also leads to unpredictable outcomes.

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Appendix A

Problem Instructions

The Triangle of Coins

Taken from Vallée-Tourangeau et al. (2020)

The triangle of coins consisted of coins arrange such that it formed a triangle pointing upwards. The goal of the problem was to rearrange the triangle in a way that it retained its same shape but would instead point down and do so by only moving three coins (Metcalfe, 1986). A solution to this problem required participants to move the three end coins of the triangle, the top end and the two bottom ends. The two bottom end ones would be moved from the base to between the middle coins on the sides, and the top one to in between the remaining two coins at the bottom (see Figure 1 at introduction for a visual representation of this process).

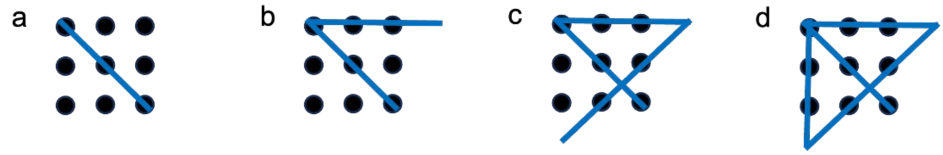
The Nine-Dot Problem

Taken from MacGregor et al. (2001)

In nine-dot problem, nine dots are arranged in a 3x3 grid formation. The participants are asked to connect all the dots using only four straight lines, which must be drawn without lifting the pen out of the paper once they commence their attempt or retracing their path. As the problem was presented in paper-and-pen, participants were given multiple sheets of paper containing several copies of the problem; this was to encourage trials without the need to worry about thinking of a solution before attempting it.

Figure A1

The Nine-Dot Problem Solution Process



The solution required participants to break the constrains of the grid space and continue the lines beyond it. Here the difficulty lied in expanding this understanding of the possibilities of the problem-solving space to go beyond the grid; as this was not indicated in the problem's instructions, the solver would have to come to this understanding by themselves. The solution process is show in Figure A1. To start, one would draw a line from the bottom-right dot straight up the top-left dot, crossing through the middle dot (Figure A1a). Then, start the second line from the top-left dot, crossing all the top dots and continuing the line beyond the grid (Figure A1b) enough so a third line can be drawn across the middle-right and middle-bottom dots until it aligns with the left column (Figure A1c). There, a fourth and final line would be drawn up to connect the remaining left-column dots (Figure A1d).